

Los Alamos SNS LINAC LOS ALAMOS NATIONAL LABORATORY LOS ALAMOS, NEW MEXICO 87545	Prepared By: Jeff Wilkinson	Date: 07 February, 2002	Technical Note: SNS02_TCN_1729	
	Approved By: N/A		Page 1/7	Rev.

Infrared Temperature Detector Recommendation for SNS D-Plate Beam Stop

Introduction

In conjunction with five other national laboratories, LANL is contracted to design and fabricate the DTL and CCL portions of an accelerator based spallation neutron source. Along with the accelerator sections, LANL is also manufacturing a beam diagnostics station or D-Plate. The D-Plate will be utilized to commission DTL tank 1.

A conical beam stop made out of nickel is mounted at the end of the D-Plate to absorb the beam energy. During normal operating conditions, the beam stop provides adequate energy dissipation through the use of water channels. However, worse case calculations have indicated that a tightly focused beam ($\varnothing 1.8$ -mm) could introduce significantly higher stress levels. To avert possible damage to the beam stop, a direct feedback system for the beam stop surface temperature was proposed.

The lack of mounting space for thermocouples on the inside of the beam stop initiated research into non-contact temperature sensors (infrared thermometers). The original requirements on the system include:

1. Fast response time (1.0-ms - ~ 10 -ms) or constant time integration
2. $\varnothing 1.8$ -mm spot sensitivity over a $\varnothing 200$ -mm field of view (FOV)
3. Ability to detect temperatures above 300- $^{\circ}\text{C}$
4. Compensation for low emissivity (≤ 0.1)
5. Implementation of feed through port to allow sighting of the inner beam stop surface
6. Ability to integrate with a computer system for triggering and analysis

With these requirements in mind, it was necessary to evaluate the different types of Infrared (IR) detectors commercially available.

IR Pyrometer Background Information

A typical IR detector contains an optical system, a detector, and the necessary electronics. The optical system is used to properly focus the photons onto the detector. The output of the detector is proportional to the energy being radiated by the target object. Due to the non-linearity of temperature with respect to radiation energy, the sensor must be calibrated for a specific temperature range. With proper calibration, the temperature of an object can be accurately inferred. To obtain an improved signal to noise ratio, the detector averages the temperature over a "time window" (typically 1.0-ms – 1.0-s). The electronics then convert the signal from analog to digital, analyze the signal (peak, average, etc.), and output the signal for recording or external device signaling. Emissivity is a measure of the thermal emittance of a surface and is defined as the fraction of energy being emitted relative to that emitted by a theoretical black body. Due to the relationship to emitted energy, emissivity is an important variable in calculating the temperature of an object accurately. (Note: For more detail see reference 13)

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Types of Infrared Detectors

Three types of IR detectors were investigated: single wavelength pyrometers, thermal imagers, and dual wavelength pyrometers. Single wavelength pyrometers measure the average temperature within the FOV and therefore cannot detect small hot spots within a larger FOV. Thermal imagers are digital cameras sensitive to the infrared spectrum. The imagers measure a temperature profile of the FOV rather than the one temperature that the single and dual wavelength pyrometers provide. The dual wavelength pyrometer uses either two rotating filters or two detector materials to take a measurement at two wavelengths. By evaluating the signal ratio of the two wavelengths, the problem of low or changing emissivity is resolved. Dual wavelength pyrometers are also particularly good at detecting a hot spot size as small as 5% of the FOV. The Omega online system provides literature^{11, 12} that explains the types of IR thermometers and their characteristics.

The single wavelength pyrometer calculates an average temperature over the whole FOV, thus a tiny hot spot would not significantly influence the overall average temperature. Even if the majority of the FOV has a temperature lower than the temperature range of the sensor, then the sensor would either indicate “Low Level” or the background interference would be too great to detect the hot spot. After a thorough investigation of single wavelength pyrometers, a determination was made that this type of sensor would not be able to detect a hot spot within a larger FOV, even if the major portion of the FOV was lower in temperature than the sensors temperature range. However, these sensors are simpler than the other types and thus are the least expensive of the three options.

To provide a temperature profile, and thus detect a hot spot, thermal imagers were then investigated. Most thermal imagers would have adequate resolution to provide an accurate temperature profile of the beam stop at approximately 640X480-pixels. Normal frame rates are around 30 – 60-Hz, however frame rates up to 1000-frames/sec (fps) or higher are available for scientific applications. They can also be interfaced with a computer program to automatically detect a hot spot within the FOV. Thermal imager technology appeared to be the best technical alternative, unfortunately the thermal imagers are cost prohibitive with most basic cameras costing over \$20k. The FLIR Thermacam SC3000 was investigated due to its capability to capture data at 900-fps, however the base cost of the system is \$80k. At this point, investigation into thermal imagers was halted and replaced with the possibility of using a dual wavelength pyrometer.

The dual wavelength pyrometer is an attractive alternative due to its ability to detect a hot spot within a larger FOV. There are two types of dual wavelength pyrometers available, a mechanical rotating filter wheel and a two material detector. The rotating filter wheel consists of two different filters that alternate through the use of a spinning disk. This provides one detector with two different wavelength signals at alternating times. The major disadvantage of this type of system is that the sensor is actually off for a period of time relative to the rotational speed of the wheel. Depending on where the wheel is oriented in conjunction with the beam triggering, the sensor could completely miss a cycle of the proton beam. This type of sensor would only be acceptable for a beam stop temperature feedback system if fitted with an external trigger. The sensor could then be timed appropriately with respect to the pulsed beam.

The second type of dual wavelength pyrometer, a dual material detector, contains a detector comprised of two types of material sensitive to different wavelengths. This sensor type has similar characteristics compared to the rotating wheel sensor without the “off period”. This establishes the possibility of using a constant integrator with the sensor. Some companies rate the extent of signal dilution that a sensor can

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tolerate and still provide an accurate temperature by the dilution ratio. The dilution ratio indicates how different the characteristics of the target object can be from the black body calibration and still have enough signal strength to take an accurate measurement. The sensor is calibrated to ideal conditions using a black body (emissivity = 1) at a known temperature and a full, uniform FOV. Depending on the sensitivity of the detector, the company then rates the sensor with the dilution ratio. A dilution ratio of 300:1 would indicate that the sensor has 300 time more infrared signal than is necessary for a accurate measurement. Factors that decrease the dilution ratio are intervening media (such as smoke, steam, dust, spray, scale or a dirty window), a partially filled FOV, and an emissivity less than one. The dilution ratio is also dependent on the object temperature, such that lower temperatures correspond to a decrease in the dilution ratio.

Results

One of the promising dual wavelength pyrometers investigated was the Raytek - Marathon Series sensor. The Marathon Series includes both ratio and standard sensors in fiber optic and integrated models. Unfortunately, the hot spot area must be greater than 5% of the FOV area for the detector to have sufficient energy for an accurate temperature reading. If the sensor FOV covers the entire beam surface ($\varnothing 20$ -cm), the smallest detectable hot spot is $\varnothing 4.48$ -cm. Likewise, the sensor would require a FOV of $\varnothing 0.8$ -cm to detect a $\varnothing 1.8$ -mm hot spot. An additional concern is the necessary time window of 10-ms to obtain 90% signal strength. To obtain proper signal to noise ratio, the sensor integrates over this time period. This means that a 1-ms pulse of energy would probably not influence the average energy during a 10-ms time window. Signal processing includes peak hold, valley hold and average along with a programmable relay output.










Conclusion

The ideal solution was complicated by the many demanding system requirements. The emissivity, a very important factor in determining an accurate temperature, of nickel at ~ 0.1 is on the low end of most infrared detectors. The proton beam, at ~ 1.0 -ms on and ~ 16 -ms off, places a high demand on the response time of the IR temperature detector. This time window might be facilitated with the use of an external trigger linked to the beam pulses to turn on the sensor. Another important factor is how large the sensors FOV can be and still have enough signal strength to detect the hot spot. Due to the system requirements, my suggestion is to use a dual wavelength pyrometer with a multi material detector. However, at this time the sensors investigated do not meet all the specified requirements.

Some possible changes to the requirements to facilitate this temperature measurement technique include: reducing the FOV necessary (possibly use more than one sensor to cover the surface), increase the emissivity of the beam stop by chemical oxidation or comparable technique, take an average measurement over more than one cycle, and/or investigate if a significant decrease in the proton beam spot size (to the mentioned $\varnothing 1.8$ -mm) would either increase the average $\varnothing 20$ -cm beam stop temperature or the temperature within a diameter > 1.8 -mm enough to indicate a problem. If a temperature increase was evident in a larger FOV than the hot spot, then the sensor could operate with a larger FOV. Taking an average temperature would also increase the necessary response time from 1.0-ms – 10-ms to the time required to complete one or more complete cycles. Given these possible changes to the requirements, a single wavelength pyrometer may become feasible.

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Table 1: Comparison of the different types and models of IR sensors researched

Single Wavelength	Model	Response time	Various Characteristics	Temp Range(°C)	Price	Rejection Reason
Omega	 OS1513	0.3 – 60 ms	Fiber optics	55-3500	2645	Unable to detect hotspot
Pyrometer Instrument	 Pyrofiber Lab	1 ms	Fiber optics, corrects for emissivity	250-700	NA	Small FOV and unable to detect hotspot
Dual Wavelength						
Mikron	 M77/78	40 ms	Control system, fiber optics, and lenses	Various	NA	Inadequate sensitivity
Williamson	 Pro 90	50 ms	Designed for hot spot detection	Various	NA	Rotating filter causes 12ms off period / can't be triggered
Raytek	 Marathon FA1/FA2	10 ms	Lenses and fiber optics	600-1400	<10k	Hot spot must fill 5% of the FOV
Thermal Imaging						
Land Infrared	 FTI 6	20 Hz / 5 ms	Rugged, lenses, program provided	-20 - 2000	35 k	Cost prohibitive
FLIR	 Thermacam SC 3000	900 Hz / 1.1 ms	LabVIEW drivers, high resolution	-20 - 500	80 k	Cost prohibitive
IRCON	 Stinger	30 Hz / 33.3 ms	Harsh environments	0-1000	>60 k	Cost prohibitive
Indigo Systems	 Phoenix	120-345 fps 8.3-2.9 ms	Complete system including DAQ	Various	103 k	Cost prohibitive

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MARATHON FR1



Thermalert®

MARATHON FR1

The Marathon FR1 FiberOptic ratio thermometers measure temperatures from 500 to 2500°C (932 to 4532°F). These thermometers consist of a rugged fiber optic cable plus optical head assembly connected to a housing. The housing contains a detector, processing electronics, internal user-interface/LED display, and termination connections for field wiring. FR1 thermometers permit measurement of targets in harsh industrial environments that are otherwise inaccessible, very hot, or located within strong electromagnetic fields.

The accuracy of FR1 thermometers varies less than $\pm 0.1\%$ of temperature over the ambient operating range of the electronics from 0 to 60°C (32 to 140°F).

The fixed-focus optical head consists of a small stainless steel cylindrical housing and achromatic lenses capable of withstanding ambient temperatures up to 200°C (392°F). The optical head accommodates an air-purge accessory to prevent lens contamination. The field-replaceable fiber optic cable is protected by metal armor and sealed with a Viton® jacket to prevent wicking of water or oils.

Included is Marathon Support Software, a suite of Windows® programs allowing parameter setting, data acquisition, graphic data display, and RS-485 multidrop network configuration.

Highlights:

- Fiber optic cable field-replaceable without blackbody recalibration
- High accuracy: $\pm 0.3\%$ of temperature $\pm 1^\circ\text{C}$
- Measures from 500 to 2500°C (932 to 4532°F) with three models
- High optical resolutions ($>60:1$) for measurement of small targets
- One- or two-color operation (unique feature)
- Fast response time down to 10 mSec
- Bi-directional RS-485 communications (networkable)
- Supports up to 32 Marathon Series sensors on a multidrop network
- Programmable relay output (dual-temperature setpoints or "fail safe")
- Simultaneous analog and digital outputs with user-defined alarms
- Unique "dirty window" alarm (attenuation measurement) (U.S. Patent No. 5,815,410)
- Field Calibration Software
- Windows® Marathon Support Software (operates under WIN 3.1/95/98/NTv4)
- Provides accurate measurement of targets that are
 - Partially occluded
 - Obstructed by smoke, steam, or particulates
 - Moving
 - Smaller than the instrument field of view

Measurement Specifications

Models:	Temperature Ranges:
FR1A	500 to 1100°C (932 to 2012°F)
FR1B	700 to 1500°C (1292 to 2732°F)
FR1C	1000 to 2500°C (1832 to 4532°F)
Detector	Si/Si-layered detector, nominal 1 µm
Accuracy	
No attenuation	± (0.3% T _{meas} ±1°C); T _{meas} in K;
Up to 95% attenuation	± 0.9% T _{meas} ; T _{meas} in K; FR1A and FR1B
Up to 95% attenuation	± 1.3% T _{meas} ; T _{meas} in K; FR1C
Repeatability	±1°C
Temperature Resolution	±1°C or °F
Response Time	10 mSec; selectable to 10 sec
Emissivity (one-color)	0.1 to 1.0 in 0.01 increments
Slope	0.085 to 1.150 in 0.001 increments
Signal Processing	Peak Hold, Averaging

Electrical Specifications

Outputs	0/4-20 mA; RS-485, 2-wire/4-wire, networkable to 32 sensors; Relay (48V, 300 mA, response time < 2 mSec)
Power Supply	24 VDC, 500 mA, ±20%
Cable	Supplied by customer; Supplied by Raytek as option
Compliance	CE low voltage directive

General Specifications

Environmental Rating	NEMA-4 (IEC 529, IP 65)
Ambient Temperature Range:	
Electronics housing (operating)	0 to 60°C (32 to 140°F)
with water-cooled option	0 to 150°C (0 to 300°F)
Fiber cable/Optical head	0 to 200°C (32 to 392°F)
Storage Temperature:	
Electronics housing	-20 to 70°C (-4 to 158°F)
Relative Humidity	10% to 95% non-condensing
Shock (Electronics Housing)	MIL-STD-810D (IEC 68-2-27)
Vibration (Electronics Housing)	MIL-STD-810D (IEC 68-2-6)
Weight:	
Electronics Housing	0.71 kg (25 oz)
Optical Head	0.10 kg (3 oz)
Cable protection	Rated to 200°C; stainless steel armor; Viton® coated; NEMA-4; provision for conduit to protect fiber cable

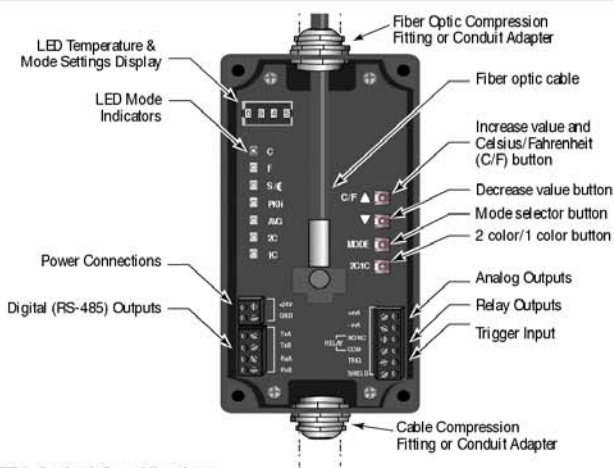
Accessories / Options*

- 24 VDC power supply
- Cooling platform*
- Air purge collar
- Conduit air purge fitting
- Sighting tube conduit accessory
- Raytek 12-conductor cable
- Raytek 4-conductor cable
- High intensity aiming lights
- Raytek Smart RS-232/RS-485 Converter
- NIST traceable certification
- Focusing options: SF, CF1, CF2
- Fiber optic cable lengths:*

1, 3, 6, or 10 m (3.2, 10, 19.2, or 32 ft)

* Must be specified at time of order

FR1 Built-in Interface and Display



FR1 Optical Specifications

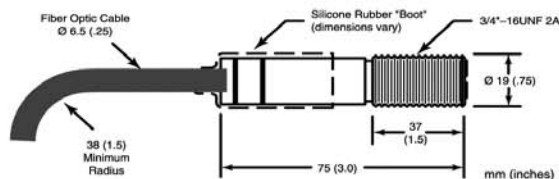
Models	D:S (Min)*	CF1	CF2	SF
FR1A	20	100 mm (4 in)	300 mm (12 in)	
FR1B	40	100 mm (4 in)	300 mm (12 in)	
FR1C	65	100 mm (4 in)	300 mm (12 in)	

* At 90% energy

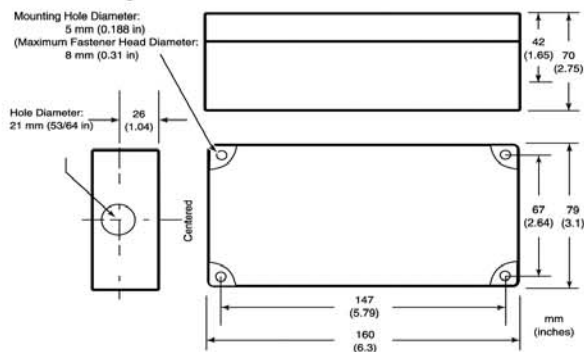
CF = close focus; SF = standard focus

General Dimensions

Optical Head



Electronics Housing



Specifications subject to change without notice.



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